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MASTER

EXPERIMENTAL INVESTIGATION OF A SUPERCONDUCTING NIOBIUM X-BAND
DEFLECTING CAVITY AND SUGGESTIONS FOR THE DESIGN OF THE DEFLECTORS
FOR A SUPERCONDUCTING RF BEAM SEPARATOR AT NAL

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Abstract

Design considerations for a deflecting cavity intended for a superconducting rf beam separator at NAL are reviewed. The design parameters given are based on an investigation of a 7-cell niobium test deflector operating at 8.665 GHz. Peak magnetic field of 740 G, corresponding to a peak electric field of 25 MV/m, and an equivalent deflecting field of 6.9 MV/m were obtained.

I. INTRODUCTION

Separated beams for the energy range available at the NAL accelerator e.g., 100 GeV/c K-beams, have been studied in considerable detail by Lach.¹ Counter experiments require long-pulse operation which would be feasible, at least in principle, by using superconducting deflectors. It was estimated that X-band structures of 3 m length and capable of 6 MV/m equivalent deflecting field would yield adequate separations.² Alternate approaches based on a sequence of short normal deflectors³ (10 x 0.65 m with ~ 0.8 MV/m) or dielectric loaded waveguides⁴ (31 m with 160 kV/m) have been considered.

A separator using two superconducting niobium deflectors (2.73 m with 2 MV/m) is under construction at Karlsruhe.⁵ It will be used at CERN II in a 10-30 GeV/m beam line to the Omega spectrometer. The operating frequency is 2.856 GHz and the intercavity spacing will be 100 m. It is expected that improvements will increase the deflecting field to 4 MV/m thereby extending the useful separation range up to 40 GeV/c.

Recently the interest in separated beams at NAL has revived. To provide the information needed in the beam design, in particular the deflecting fields achievable at X-band frequencies, an experimental study was carried out at Brookhaven on account of NAL. A 7-cell niobium deflector was designed,

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1. J. Lach, "200 BeV Accelerator Studies on Experimental Use", Vol. 1, p. 190, UCRL Report No. 16830, Berkeley, Calif. (1966).
 2. J. Lach, NAL 1968 Summer Study, Vol. 3, p. 209.
 3. H.J.W. Foelsche, NAL 1969 Summer Study, Vol. 1, p. 119.
 4. J. Sandweiss, NAL 1969 Summer Study, Vol. 1, p. 125.
 5. W. Bauer, A. Citron, G. Dammertz, M. Grundner, H. Lengeler and W. Rathgeber, Proc. 1973 Conf. on Instrumentation for High Energy Physics, Frascati, Italy, May 8-12, 1973.

fabricated and tested. In this report we present the results of our tests and give recommendations for the design and fabrication of a full size X-band deflector. An estimate of the performance to be expected from superconducting X-band deflectors is also given.

II. GENERAL DESIGN CONSIDERATIONS

With the operating frequency fixed at a value below 10 GHz (we take 8.665 GHz to fit our measuring equipment), the outer diameter of the cavity is given and one has to choose first the mode which determines the iris distance. The aperture and the iris thickness, for a given mode, influence the shunt impedance, the sensitivity to fabricating tolerances, the peak fields, and the acceptance. The latter is, of course, also given by the overall cavity length of about 3 m which has been chosen according to the necessary deflecting angle at achievable deflecting fields.

1. Operating Mode

The choice of the mode is a compromise between the need of a high shunt impedance and the sensitivity to fabricating tolerances. At the $\pi/2$ -mode, the group velocity is high and the tolerance requirements are easier to meet than in the π -mode, where the group velocity is zero. Furthermore, in the $\pi/2$ -mode every second cell has nominally zero field providing the possibility of joints between the sections of a long cavity. At X-band, however, the iris distance in the $\pi/2$ -mode would become very small giving rise to fabrication difficulties, peak field, and multipactoring problems. A suitable location for joints in a π -mode structure can be found in a π -mode-like multiperiodic structure, where at the joint one iris is omitted. (See Ref. 6.) The shunt impedance of such a structure is only slightly less than that of the π -mode and considerably higher than in the $\pi/2$ -mode. The tolerance requirements can be met as will be shown in Chapter III.

2. Aperture and Iris Thickness

The aperture influences mostly the group velocity. There are two possible ranges, as shown in Fig. 1. At fairly small diameters, the group

6. G. Dammertz, Thesis, Kernforschungszentrum Karlsruhe (1973).

7. W. Bauer, BNL Informal Report AADD 73-4 (1973).

velocity reaches a negative maximum and with increasing diameter it approaches at first zero and rises then to usable high positive values. In Ref. 7, it is shown how by this choice of iris diameters the shunt impedance and hence the required rf power and the necessary cavity lengths are influenced. In Ref. 7, it is also shown that the acceptance is not much affected by the choice of the iris diameter in a first approximation, although this point has to be investigated more thoroughly taking into account the design of a real beam, which is beyond the scope of this report.

Fig. 1. Group velocity/ c as function of iris diameter (π /mode, iris thickness $t = 3.3$ mm).

The iris thickness can be chosen by the demand of a minimum ratio H_p/E_0 for a given aperture and a given mode.⁸

3. Mode Stabilizers

Due to machining and fabricating tolerances in a typical cylindrical iris loaded cavity, it is possible for the transverse deflecting fields to become elliptically polarized, resulting in a rotation of the deflecting fields along the length of the structure. To prevent this mode rotation, mode stabilizers must be used, which disturb the cylindrical symmetry of the cavity. It is essential that a sufficient frequency separation is achieved between the operating mode and the mode oscillating in the direction perpendicular to the wanted deflection. As shown in Refs. 9 and 10, this can be done by a slightly elliptical shape of the cavity's cross section. Fabricating problems resulting from this demand are dealt with in Chapter IV.

4. Joints

As the whole cavity will have a length of about 3-5 m, the necessity of heat treatments in an available furnace requires short sections which have to be assembled to give the whole cavity. Although its joints are located at places of nominally zero currents, fabricating tolerances give rise to some currents which may affect the resulting Q-values. It is an open question whether a technical solution for the joints can be found that reduces the influence of the currents on the Q-values sufficiently or whether a careful tuning of the single sections or even of the single cells might be necessary. Some quantitative answers to this problem are given in Chapter III.

III. TOLERANCES, TUNING

Cavity dimensions differing from the nominal values arise from the following facts: The machining of the single cells can only be done with a certain accuracy. The electron beam welding gives rise to an unavoidable shrinkage of the weld, which is difficult to predict, as it depends on the particular block of niobium used. The necessary heat treatment at up to 2000°C may result in serious changes of the cavity dimensions. Not much is

8. V. Vaghin, thesis, CERN Report 71-4 (1971).

9. W. Bauer, thesis, Report Kernforschungszentrum Karlsruhe, KFK 1505 (1971).

10. J.R. Aggus, W. Bauer, S. Giordano, H. Hahn and H.J. Halama, IEEE Trans. Nucl. Sci. NS-20, No. 3, 95 (1973).

known about the magnitude of the deviations caused by the heat treatment; by carefully stress relieving before the final machining (Chapter IV) one can at least assume, that they will be almost equal for all sections. The shrinkage of the weld may introduce an uncertainty of ± 0.1 mm in the cell length. In order to prevent these errors of adding up to excessive deviations of the overall cavity length, one has to select welded cell pairs according to their length and combine them in such a way that by cancelling the errors the whole section is not more than ± 0.2 mm out of tolerance. As the diameters influence the frequency more than the length by a factor of three, it is not worthwhile to increase the accuracy of the outer diameter to better than ± 0.03 mm which can be achieved with reasonable effort.

All of these dimensional deviations can cause changes of the operating frequency and differing field amplitudes in the single cells which is most serious in the nominally field-free joint cells. These problems have been dealt with in Refs. 6, 11 and 12 for the $\pi/2$ mode. For the multiperiodic π -mode we showed in Ref. 13 that it is possible by proper pretuning of the single sections to achieve sufficient low currents across the joints. The adjustment of the operating frequency can be done with a few slow tuning pistons as described in Ref. 6. Although the iris-loaded structure can be built fairly rugged, one has to investigate the consequences of using two independent helium refrigerators at an intercavity distance of the order of 1000 m. At S-band, a distance of only 100 m allows the use of one refrigerator and the two cryostats can be connected by a liquid helium line. A pressure stability of 0.1 Torr in both cryostats is thus achievable, so that no fast tuning system is necessary (Ref. 6).

IV. FABRICATION

It is quite clear that the cavity will be fabricated by machining single cells from solid niobium and electron beam welding at the outer circumference. Other fabricating methods like hydroforming of half cells do not show any considerable reduction in material or fabrication costs in our case (especially when premachining of the cells is done by the niobium supplier) and have the disadvantage of additional electron beam welds at the critical iris edge area

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11. W. Jüngst, Report 3/69-16, Kernforschungszentrum Karlsruhe (1972).
 12. H. Hahn and D. Lazarus, BNL Informal Report 16437 (1972).
 13. W. Bauer, BNL Informal Report AADD 73-3 (1973).

Fig. 2 Niosium X-band Deflecting Cavity

Fig. 3 Geometry of Niobium Test Cavity (Dimensions in cm)

and of less mechanical stability. In order to study the fabrication process and to obtain information about the performance of an X-band cavity, we built a 7-cell deflector model which is shown in Figs. 2 and 3. The fabricating procedure of this test cavity was described briefly in Ref. 10. We repeat it here in greater detail:

The test cavity was made from solid billets of electron beam melted reactor grade niobium. (Supplier: Wah Chang). Rough machining was carried out using high speed tool steel, with a smooth top rake (no chip breakers). Typical rough machining parameters were as follows:

Depth of cut - 0.050 in.

Surface speed - 80 to 100 ft/min.

Feed per revolution - 0.001 in. to 0.002 in.

Finish machining was accomplished using an Everede C_2 tungsten carbide tool insert (Fig. 4). The groove in the tool was formed using a 0.078 in. diameter brass wire loaded with diamond dust. Typical finish machining parameters were as follows:

Depth of cut - 0.001 in. to 0.002 in.

Surface speed - 100 to 120 ft/min.

Feed per revolution - 0.0005 in.

Fig. 4. Tungsten carbide tool insert used for finish machining.

Freon 113 was used as a coolant during all machining operations. A thin stream of coolant is directed at the tool tip by means of a hypodermic needle attached to the tool (Fig. 5). Finishes of from 8 to 12 microinches are normally obtained.

The cavity parts were first rough-machined to within 0.008 in. of the finished dimensions, then heat treated for 5 hours at 1400°C in a vacuum furnace at 2×10^{-8} Torr. This preliminary heat treatment is to ensure stress relief and encourage grain growth prior to finish machining.

Figure 6 shows an end cup and an iris after heat treating and then etching in a solution of 33% hydrofluoric acid (concentration 49%), 33% nitric acid (concentration 70%), remainder distilled water.

For a step-by-step pictorial guide showing the full fabrication sequence, see Fig. 7.

The cavity was assembled and welded in such a manner as to allow the circumferential welds in the center cells and the two coupling cells to be machined relatively smooth on the inside surfaces after welding.

Figures 8a and 8b show the untouched and the remachined weld, respectively.

In Fig. 8c, the weld has been machined and chemically polished.

Many sample circumferential welds were completed in an attempt to obtain full penetration, with a slightly raised weld bead on the inside surface that could subsequently be machined smooth; however, typical results that we were able to obtain are shown in Fig. 8. This enlarged cross section shows a weld depression on both sides of the weld bead, which would have required the removal of 0.008 in. of material to ensure a smooth finish. Since this was considered excessive, the raised bead only was removed as shown in Fig. 8c. The design of a new cavity would, of course, allow for sufficient material to remove the depression completely.

The electron beam weld parameters shown in Table I apply only to the one particular filament used, as a change in filament usually results in a change in weld parameters.

Table I. Electron beam weld parameters

Weld Fig. 2	Gun/Work (in.)	I (mA)	kV	in./min
C	19	15	110	30
D	16	7	100	12
E	16	7	100	manual
F	16	10	120	12
G	16	8	100	12

Fig. 5 Tool for finish machining with hypodermic needle for applying coolant.

Fig. 6 End cup and iris after rough machining,
furnace treatment for stress relief and grain growth and etching

FIG. 7 FABRICATION SEQUENCE FOR X-BAND CAVITY

FIG. 8a
CROSS SECTION OF
CIRCUMFERENTIAL WELD

FIG. 8b
WELD AFTER MACHINING

FIG. 8c
WELD AFTER MACHINING
AND CHEMICALLY POLISHING

Shrinkage along the axis of the cavity occurred due to the circumferential welds, and averaged out at 0.005 in. per joint. Out-of-parallelism due to the circumferential welds came to a maximum value of 0.0015 in.

Machining allowances had to be made to compensate for weld shrinkage and distortion.

On completion of all electron beam welding the cavity was vacuum leak-checked, and ultrasonically cleaned in alcohol.

The test cavity was machined without mode stabilizers because the perturbation due to coupling ports removes the degeneracy completely. Actual deflectors, however, require mode stabilizers and the use of eccentric structures is being considered. A solution which appears simple to fabricate has been suggested in Ref. 10: The machining of the mode stabilizing eccentric cavity is accomplished by first machining the iris radius and 3° sloping face truly circular and symmetrical. The eccentric portion is then cut by moving the cavity off center in the lathe by 0.096 cm. The tool is then moved into the work axially at a radius of 1.906 cm to a depth of 0.198 in. The tool is then moved radially toward the center of the work until it cleared the 3° angled face. The eccentric portion, therefore, is actually a small portion of a cylinder. The process is repeated on the other half of the cavity for symmetry. This method of fabrication enables the EB welded joint to remain truly circular and of constant thickness as shown in Fig. 9.

To construct a full-size deflector would require similar steps. It is virtually impossible to build a simple tool that is small and strong enough, to fit through the iris hole, for the purpose of machining the welds. It may be possible to design an expandable tool to fit through the structure. At present the only thinkable solution is to build up the structure one cell at a time, by machining each weld before welding on the next cell.

V. RESULTS OF TEST CAVITY MEASUREMENTS

In this chapter we summarize our measurements on the test cavity described above. These results have been briefly reported in Ref. 14. Here we will give more details and draw some conclusions.

14. J. Aggus, W. Bauer, S. Giordano, H. Hahn and H.J. Halama, submitted to Applied Phys. Letters.

Fig. 9 Deflector Geometry with Mode Stabilizer
(Dimensions in cm)

1. Room Temperature Model Measurements

To evaluate the superconducting breakdown fields in a cavity from a measurement of the Q-value and the power P dissipated, one needs the constant C_H entering the relation

$$H_p = C_H \sqrt{Q P}$$

with H_p in G and P in W, and the ratio peak electric field to peak magnetic field E_p/H_p . They were determined by room temperature model measurements which will be now described.

Two aluminum models were fabricated and measured using the perturbation method. One of them was a model of the actual X-band cavity which was scaled to 3 GHz for measuring convenience. It shows a fairly distorted field distribution (Fig. 10) due to the heavy perturbation of the fields by coupling holes and beam tubes. Therefore, only the 0-mode and the $2\pi/3$ -mode, in which a predominant field maximum occurs in the center cells were suitable to determine breakdown fields. In order to relate the numbers measured to an ideal cavity, where all perturbations are compensated, we measured also the field distribution of a model without coupling holes and beam tubes. During the experiments with the superconducting cavity, it turned out that one would like to know the ratio of the maximum magnetic field at the electron beam weld compared to the peak magnetic field at the iris H_w/H_p . We measured this ratio by pulling a metal hemisphere around the iris and along the path from one iris to the next on the outer diameter perpendicular to the electron beam weld. According to a few measured points, this ratio is smallest in the π -mode, adding one important argument more in favor of using the π -mode rather than the $\pi/2$ -mode. The results of these room temperature model measurements are shown in Table II.

TABLE II. Result of room temperature model cavity measurements.

	Mode	C_H	E_p/H_p (MVm ⁻¹ /G)	H_w/H_p
Actual	0	$\times 10^{-3}$ 20.9	0.397	0.787
	$2\pi/3$	28.6	0.397	0.638
Ideal	π	21.0	0.423	0.391

Fig. 10. Axial field component in test cavity as measured by a perturbing needle along the path indicated.
(Solid line: $2\pi/3$ -mode; dashed line: 0-mode)

2. Measurements at Low Temperatures

We feel it interesting enough to present in this report the complete history of the niobium test cavity. The results of all low power Q-measurements are shown in Table III, the breakdown fields and high power Q-values are given in Table IV. To properly interpret the available data, some remarks and explanations seem necessary:

We use a standard cavity treatment procedure which consists of the following steps:

cp: chemically polishing with a solution of 40% HF (concentration 49%) + 60% HNO₃ (concentration 70%), at approximately 0°C for 20-30 sec.

ht: heat treatment at 1850°C and about 2×10^{-8} Torr for about 20 h.

a: anodizing with 95 V in diluted - H₂SO₄ (concentration 0.25% by volume).

To ensure complete chemical polishing of all internal surfaces the cavity is rough vacuum pumped prior to flowing through the chemical solution. After chemical polishing the cavity is thoroughly rinsed in distilled water, and stored in methanol until ready for the vacuum furnace run.

In Tables III and IV, the treatments preceding the measurements are indicated by the abbreviation cp, a, ht.

TABLE III. Low level Q-values at 1.5 K

Measurement	Q $\times 10^{-6}$						Preceding Treatment
	0	$\pi/6$	$\pi/3$	$2\pi/3$	$5\pi/6$	π	
0	3.7	-	-	110	-	-	cp, a, ht
1	367.1	126.9	123.9	364.4	261.9	124.9	a, ht
1b	228.6	119.6	199.3	236.7	121.5	38.0	warm up to 300 K
2	864.9	407.6	691.9	898.5	438.1	142.6	a, ht
3	2381	1463	3639	2465	1806	4582	cp, at
3b	908	499	1139	1029	326	1518	cp, ht
3c	16.4	13.3	13.6	15.6	7.8	14.9	tu, cp, ht
3c	-	-	-	61.1	-	-	ht
4	1489	795	1588	1556	256	704	cp, a, ht
4b	818	420	769	880	145	404	after 100 min. at high power

TABLE IV. Fields and Q-values at high power

Run	2 π /3-Mode			.0-Mode			Preceding Treatment
	H _p (G)	H _w (G)	Q _o × 10 ⁻⁶ at H _p	H _p (G)	H _w (G)	Q _o × 10 ⁻⁶ at H _p	
0	-	-	-	-	-	-	cp, a, ht
1	743	473	535	572	450	521	a, ht
1a	691	440	405	410	324	275	½ hour later
1b	500		192	554		207	warmed up to 300 K
2	601	383	359	486	383	737	a, ht
2a	-			430		703	½ hour later
3	691	440	1064	398	313	1669	cp, a, ht
3a	686	437	1268	395	310	805	2. measurement same day
3b	>249		718	340		849	cp, ht
3c	-		-	-		-	tu, cp, ht
3d	-		-	-		-	ht
4	577	368	407	500	393	673	cp, a, ht
4a	480		383	-			½ hour later
4b	475		266	-			2 hours later

TABLE IV. Fields and Q-values at high power

2 π /3-Mode		0-Mode			Preceding Treatment
H _w (G)	Q _o × 10 ⁻⁶ at H _p	H _p (G)	H _w (G)	Q _o × 10 ⁻⁶ at H _p	
-	-	-	-	-	cp, a, ht
473	535	572	450	521	a, ht
440	405	410	324	275	½ hour later
	192	554		207	warmed up to 300 K
383	359	486	383	737	a, ht
		430		703	½ hour later
440	1064	398	313	1669	cp, a, ht
437	1268	395	310	805	2. measurement same day
	718	340		849	cp, ht
	-	-		-	tu, cp, ht
	-	-		-	ht
368	407	500	393	673	cp, a, ht
	383	-			½ hour later
	266	-			2 hours later

After run 0, no measurement was performed because it was not possible to withdraw the coupling loops far enough, resulting in a strong overcoupling. After fabricating spacers to extend the length of the coupling tubes we were able to measure the results shown as run 1. Note the apparent difference in H_p of the both modes and the agreement of H_w . The deterioration of the results in run 1a had taken place about half an hour after measuring run 1, resulting now in different values of H_w . Run 1b was measured a few days later without opening the cavity. However, during warm-up, the vacuum inside is believed to have become bad which could, by contamination, have caused the somewhat lower peak fields. This assumption is supported by the observation that, during the subsequent anodizing process, the cavity showed a strange behavior: it took one hour to anodize compared to the normal ten minutes, and a large amount of gas bubbles appeared on the cavity which is unusual.

Run 2 almost restored the previous result, especially the striking similarity of H_w in both modes. When we tried to repeat this measurement in run 2a, after measuring the 0-mode, suddenly the cavity deteriorated and it was no longer possible to feed any power into it. This observation of a high field for a short time and a sudden decrease of the field was even more pronounced after run 3a, where both modes had deteriorated. Whereas the damage could be cured by our standard surface treatment after runs 1b and 2a, it was not possible to restore the cavity after run 3a. In run 3b the damage was apparently present already before the first application of rf power. therefore, decided to give the cavity the following tumbling treatment (tu) after run 3b: the cavity was half filled with crushed and sieved Almco tumbling media 114 P in a solution of 500 cm³ distilled water, 5 cm³ Almco 2220 cleaning compound and 10 cm³ of Almco 408 silica flour. It was then rotated at 70 rpm for 200 hours. The tumbling operation was stopped once a day to enable the old solution to be flushed out with methanol and replaced with fresh solution. The resulting surface finish is mat and gives a reading of 8 microinches. Chemical polishing is required to bring back the required lustre to the tumbled surface. Runs 3c and 3d show that there was at first not enough chemical polishing after the tumbling. Finally run 4 restored almost the results of run 1. Again, a small deterioration was observed in run 4a, but a continuous operation at maximum power level for 2 hours produced no further damage, as shown in run 4b. (In runs 4a and 4b only the $2\pi/3$ -mode was measured.)

To summarize the cold measurements, we would like to make the following statements:

Q-values. Whereas the Q-values at 4.2 K are almost equal, the low level residual Q's vary considerably both from mode to mode and from one measurement to the other. The mode dependence is due partly to the heavy distortion of the

fields and partly to the inhomogeneous surface resistance caused by the electron beam welds and other surface irregularities. It is apparent that improved surface treatment procedures are required. A better understanding of the physics of rf-superconductivity would undoubtedly result in improved methods.

At high power, the Q-values are usually lower than the low level residual Q-values by about a factor of two. In one case, (run 1), the Q-value increased with rf power, which indicates a very good surface.

Despite the wide range of Q-values measured, we feel that the measurements have shown that a Q-value of about 5×10^8 could be reached safely by the present technique, which is already enough to build a separator with reasonable low rf power consumption.

Peak fields. Regarding the peak fields, three observations were made:

1. The peak fields obtained were considerably higher than those at S-band. There are some considerations which suggest that due to the smaller size of high frequency cavities, the probability of surface defects is lower, resulting in higher fields.^{15,16} Also, if one assumes that magnetic breakdown can be initiated by electrons, higher frequencies are superior because electrons have not enough time to get sufficient high energies.¹⁷ We feel, however, that imperfect electron beam welds might be one reason for breakdown, and by remachining some of the welds, we could have increased the fields.

2. This assumption, concerning the breakdown at the welds, is also supported by the following observation: the difference between the peak fields in the $2\pi/3$ - and 0-modes which was observed in several measurements was at first surprising because the peak field occurs in both cases at the same place, namely the iris edge. Since we could show that the corresponding field amplitudes at the electron beam welds are in most runs equal, we concluded, that in these cases the breakdown took place on the welds rather than on the irises.

3. One cannot, however, state that the breakdown always occurs at the weld, because we observed exceptions to this rule. We think that these are explained by the third observation we made: it was possible to destroy the cavity surface so that no high fields could be reached after a very short run at high power. We assume that this degradation is due to radiation damage caused by electrons hitting the cavity walls. In one case, after measurement 4a, we measured the low power residual Q again and found a reduction of all Q-values by a factor of about 2, which is also an indication for radiation damage.

15. J.P. Turneure, Proc. 1972 Appl. Superconductivity Conf., Annapolis, Md., 521 (1972).

16. P.B. Wilson, Proc. 1972 Proton Linear Accel. Conf., Los Alamos, 82 (1972).

17. J. Halbritter, Particle Accelerators 3, 163 (1972).

The degradation in run 3a could not be cured by firing or by chemically polishing and firing. However, we could restore the cavity by tumbling and heavy chemical polishing plus firing. As we were able to run the cavity for 100 minutes without deterioration after the tumbling at a peak field of approximately 500 G and since most of the remaining measurements yielded higher fields, we assume this value as a safe lower limit for the obtainable fields in a steady state operation.

VI. PROPOSED CAVITY PARAMETERS.

Based on the measurements described above, we propose the cavity parameters in Table V. Two versions are indicated which differ by the overall length. The length of the single sections is determined by the hot zone of the UHV-furnace to be used; we chose it to be about 60 cm according to the BNL furnace. As is shown in Ref. 13, the whole cavity has to be constructed of an uneven number of sections, leading to the two versions with five or seven sections respectively. Iris diameter and iris thickness are the values used in our 7-cell model described above for which we have measured the field ratios and shunt impedance given in the table. Reference 7 describes some of the modifications to these figures if one considers a larger aperture.

The equivalent deflecting field of 4.7 MV/m is derived in the following way from our measurements: If we assume to be able to achieve 500 G in an ideal π -mode cavity at the iris, we calculate from the measured $H_p/E_o = 107 \text{ G/MV m}^{-1}$ a deflecting field $E_o = 4.7 \text{ MV m}^{-1}$. This corresponds to a field at the weld of $H_w = 200 \text{ G}$ which is certainly on the safe side.

VII. CONCLUSION

A design study for an X-band deflecting cavity based on calculations and test measurements has been presented, which might add some arguments in a discussion whether a superconducting particle separator for high momenta should be constructed. It would have been useful to work out a rough cost estimate but this was outside the scope of this work. Before entering the construction, however, some additional investigations should be undertaken: As a first step, a larger test cavity with mode stabilizer and with compensation for beam tubes and coupling ports should be built. Our observation concerning the electron beam welds and the radiation damage should be investigated more thoroughly. To improve the surface quality, a method for electropolishing small iris loaded structures has to be developed. Superconducting joints and their influence on Q-values and peak fields should be investigated. Model measurements with a large iris

TABLE V. Design parameters for a multiperiodic π -mode-like X-band deflecting cavity

Frequency, (GHz)	8.665	
Cell length, (mm)	17.3	
Iris thickness, (mm)	6.7	
Iris hole diameter, (mm)	13.3	
Magnetic field ration H_p/E_o , (G/MV m ⁻¹)	107	
Electric field ratio E_p/E_o	3.63	
Peak magnetic field on iris H_p , (G)	500	
Peak electric field on iris E_p , (MV/m)	17	
Equivalent deflecting field E_o , (MV/m)	4.7	
Shunt Impedance/Q, (Ω /m)	4730	
Improvement factor	5×10^4	
Shunt impedance, (M Ω /m)	2.13×10^6	
Number of sections	5	7
Total length, (m)	2.29	3.43
Number of cells, middle section	3 x 33	5 x 33
Number of cells, end sections	2 x 16½	2 x 16½
Transverse momentum per cavity, (MeV/c)	10.8	16
rf power loss per cavity (W)	24	36

diameter cavity would be interesting. In order to obtain a reliable optimization of multiperiodic structures, theoretical studies should be intensified.

Although we believe to have demonstrated that a superconducting X-band separator can be built with the present status of technology, it is obvious that a more thorough investigation of rf-superconductivity with the result of more reliable recipes for cavity treatment could be extremely helpful.

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